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A REVISED DIAMOND BOOSTER DESIGN

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Abstract

Since the initial concept for the DIAMOND 3 GeV booster synchrotron was published [1] a number of new requirements, such as the capability to operate in a 'top-up' mode and major changes to the design of the main storage ring, have led to significant modifications to the specification [2]. The DIAMOND booster lattice is now a compact, two-fold missing dipole design with 44 cells and a circumference of approximately 157 metres. The missing dipole sections are to contain the extraction, injection and RF systems. It will be located in a separate building within the DIAMOND storage ring to enable entirely independent operation of the two rings. The booster will require the use of advanced switched-mode power supply technology and a normal conducting, multi-cell RF cavity. Aperture calculations and injection and extraction schemes are also presented.

1 INTRODUCTION

The DIAMOND booster synchrotron is a two-fold symmetric missing dipole magnet design. The missing dipole sections are to accommodate the injection and extraction system as well as the RF system. There are 36 dipole magnets and 44 quadrupole magnets in the entire lattice. The requirement for sextupoles; either only at injection or throughout the ramp cycle, has not yet been fully assessed. A major factor will be the eddy currents induced in the metallic vacuum chamber. The chamber wall thickness and the booster repetition rate have not yet been finalised. It is assumed that the beam is injected into the booster at 100 MeV and ramped up to 3 GeV with a repetition rate of ~5 Hz.

2 ACCELERATOR PHYSICS

Work has been carried out in designing the lattice, choosing a tune point, specifying the dipole half aperture and designing an injection and extraction scheme [2].

2.1 Lattice

The total circumference of the booster is 157.2 m. Each super-period comprises of three different types of cell, A, B, and C, shown in Figure 1. Arranging the cells in the following order forms one super-period of the booster:

A – A – C – C – C – C – C – C – C – B – B

The chosen tune point is at Q_x = 6.83 Q_y = 4.57. Table 1 gives magnet and machine parameters at this tune. The corresponding lattice functions are shown in Figure 2.

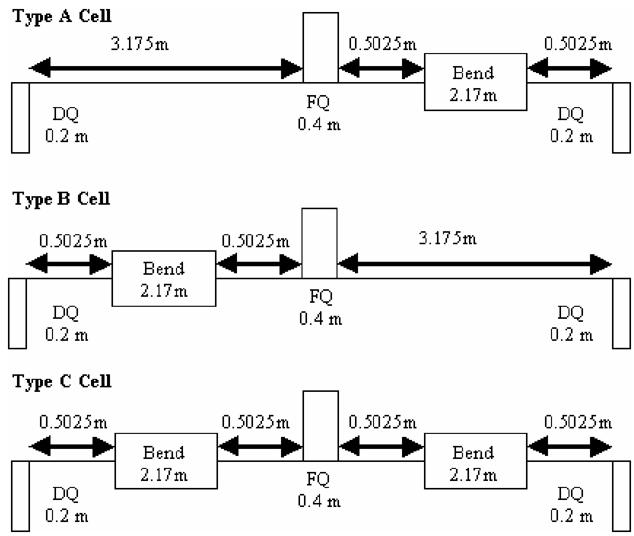

Figure 1: Cells used in the booster lattice.

Table 1: Parameters at design tune point and 3 GeV

Dipole Field	0.804	T
F-Quadrupole Field	11.50	T/m
D-Quadrupole Field	-9.44	T/m
Momentum Compaction Factor	0.027	
Energy Loss/turn	576	keV
Radial Oscillation Damping Time	5.4	ms
Vert. Oscillation Damping Time	5.5	ms
Energy Oscillation Damp. Time	2.7	ms
Vertical Chromaticity	-6.21	
Horizontal Chromaticity	-8.35	
Radial Emittance	144	nm rad
Quantum Lifetime	~45	s

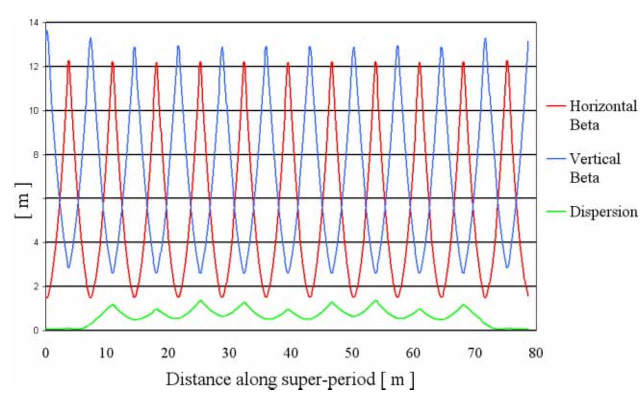

Figure 2: Booster lattice functions.

2.2 Injection

The injection system, consisting of a kicker and septum, fits into two successive missing dipole sections of the booster lattice. The magnet properties are summarised in Table 2. Figure 3 shows the layout of the injection scheme.

Table 2: Injection magnet properties.

Element	Angle (mrad)	Length (mm)	Field (mT)
Kicker	12	650	6.15
Septum	262	300	300

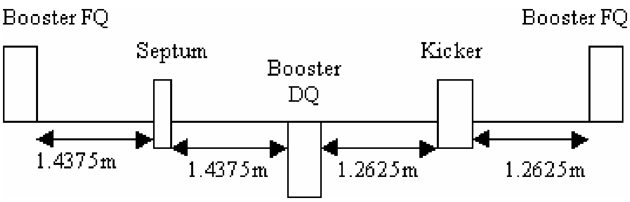

Figure 3: Layout of the booster injection scheme.

2.3 Extraction

The extraction magnets are positioned in three of the missing dipole cells. Three slow kickers create a closed orbit bump, then the beam is extracted in one turn using a fast kicker and two pulsed septa magnets. Table 3 gives the extraction system magnet parameters.

Table 3: Extraction magnet properties.

Magnet Type	Nominal Deviation (mrad)	Length (mm)
Slow Kicker (SK)	2.9	720
Fast Kicker (FK)	1.5	720
Pre-Septum (PS)	8	360
Main Septum (MS)	110	1200

The layout of the extraction elements in the booster missing dipole lattice is shown in Figure 4. The beam displacement up to the end of the main septum is shown in Figure 5. At the end of the septum the beam is displaced by approximately 100 mm and 120 mrad.

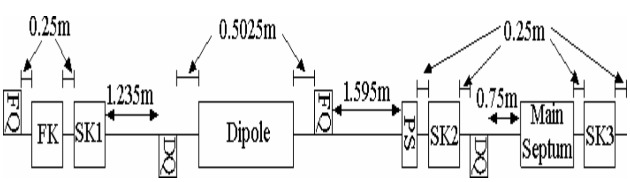

Figure 4: Extraction system layout

2.4 Dipole Apertures

It has been assumed that at injection into the booster the radial and vertical emittance of the beam from the linac is 1000 nm rad. The momentum spread is assumed to be 0.15%. From these assumptions, and the lattice functions, the beam sizes were calculated and are shown for one super-period in Figure 6.

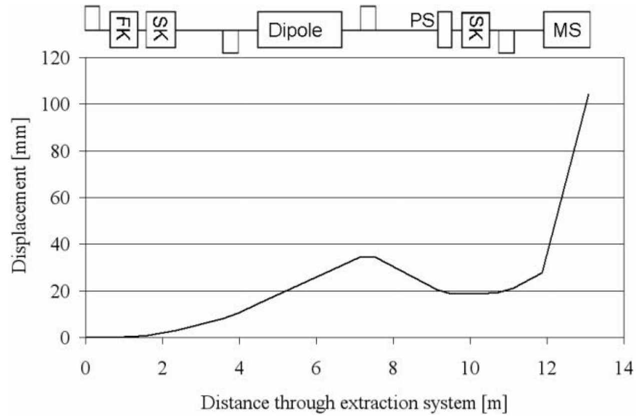

Figure 5: Beam displacement through the extraction system.

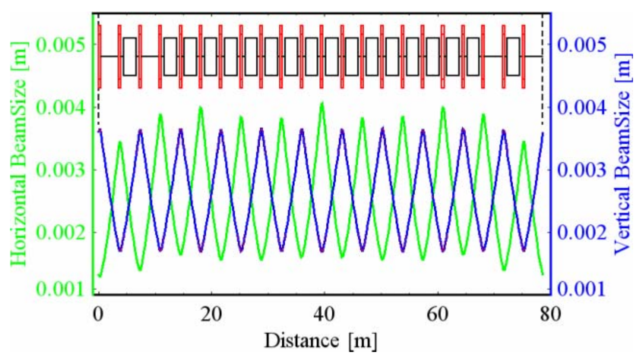

Figure 6: Beam sizes at injection through one super-period.

The maximum beam size through the dipole is 3.5 mm horizontally and 3.3 mm vertically. The closed orbit distortion due to random magnet misalignment errors in the design lattice was calculated. The type and standard deviations of the errors are shown in Table 4.

Table 4: Standard deviations of assumed magnet errors.

Quad Transverse Displacement	0.1	mm
Dipole Transverse Displacement	0.05	mm
Dipole Longitudinal Displacement	0.05	mm
Dipole Field Error	0.1 %	
Quadrupole Roll Error	0.2	mrad
Dipole Roll Error	0.2	mrad

The maximum values of the closed orbit, both horizontal and vertical, were modelled over 300 error sets, at the centre and the ends of each element in the lattice. For the dipole aperture we are interested in the maximum of the 95% confidence limit of the closed orbit errors through all of the dipoles in the lattice. This is 6.9 mm horizontally and 1.7 mm vertically. The assumed half aperture required is then equal to three times the maximum beam size through the dipole, plus the largest value of the 95% confidence limit closed-orbit error through the dipoles. The resultant half-aperture requirements in the horizontal and vertical planes are calculated to be 17.5 mm and 11.5 mm respectively.

3 RF SYSTEM

The required accelerating voltage for a booster synchrotron is largely dependent on the required quantum lifetime and the momentum compaction, both given in Table 1. The RF is rated to allow up to 20 mA beam current in the booster. The design is dominated by the 3 GeV requirements; Table 5 gives the main parameters of the proposed RF system for the booster synchrotron.

Table 5: DIAMOND booster RF system parameters.

RF Frequency	499.654	MHz
Loss/turn	576	keV
Overvoltage	1.9	
Cavity (number of cells)	5	
Cavity Shunt Impedance	12.4	MΩ
Accelerating Voltage	1.1	MV
Synchrotron Frequency	~30	kHz
Beam Power (@ 20 mA)	11.5	kW
Cavity Power	48.5	kW
Total RF Power (inc. losses)	66	kW

A suitable multi-cell cavity, with 5 cells and a shunt impedance of around 12 MΩ, would be a modified PETRA cavity such as to be used by the Canadian Light Source and ELETTRA boosters. The power source would be one of the modules that will be used in the Storage Ring RF system.

4 POWER SUPPLIES

A more detailed account of the booster dipole power supplies is given elsewhere [3]. The booster synchrotron will be capable of working in an injection top-up mode. This leads to a strong preference for a switch-mode power supply solution. It will provide greater flexibility and operational economy plus lower capital cost. A similar solution has been implemented by the SLS [4]. Power semiconductor technology has advanced sufficiently to make this option feasible for DIAMOND.

Finite element analysis of a dipole geometry has been carried out [2]. The total flux cutting the coil is indicated by the value of the vector potential at the centre of the coil. Table 6 gives the data from this analysis

Table 6: Flux values from FEA modelling.

Predicted vertical induction at origin	0.839	T
Predicted flux cutting at coil centre	0.0468	webers/m
Effective flux width across pole	112	mm

With the flux cutting the coil now determined, the reactive power rating of the dipole power supply can be established and the impedance match between magnet and power supply considered.

Coil and power supply parameters based on two possible choices of turns on the dipole are presented in Table 7. The final choice of the power supply design and impedance level will be made after further discussions with manufacturers.

Table 7: Magnet coil and power supply parameters for the booster dipole, for two options of numbers of turns per dipole.

Parameter	low turns	high turns	
Number of turns per dipole	16	20	
Peak current	1271	1016	A
D.C. and peak A.C. component	635	508	A
Total rms current (for fully biased sinewave)	778	622	A
Conductor cross-section	195	156	mm^2
Cooling channel diameter	5	5	mm
Conductor width	14.5	13.5	mm
Conductor height	14.8	13.0	mm
Total ohmic loss	188	188	kW
Inductance per magnet	2.52	3.94	mH
Inductance (all dipoles in series)	0.091	0.142	H
Peak stored energy (all dipoles)	73.3	73.3	kJ
Cycling frequency	5	5	Hz
Peak reactive alternating voltage across circuit	1.81	2.26	kV

The parameters in Table 7 are not finally frozen, since the various options for the procurement of the booster synchrotron may lead to adjustments in lattice and engineering design. However, such changes will certainly not result in any significant increase in ratings or dimensions. Hence the voltage and current figures presented above are not expected to be exceeded when the final design is established.

It is concluded that the present excitation requirements can be met using a switch-mode power converter design and that the booster magnets should be powered by such a switch-mode system, using electrolytic capacitors for energy storage and with a cycling repetition rate of ~5 Hz.

5 REFERENCES

[1] 'DIAMOND Synchrotron Light Source: Report of a Feasibility Study', Daresbury Laboratory, 1997.

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[3] N.Marks, et al; 'Configuration of the Dipole Magnet power supplies for the DIAMOND booster synchrotron', these proceedings.

[4] W. Joho, et al; 'The SLS Booster Synchrotron', Proc. of the 6th European Particle Accelerator Conference, Stockholm, June 1998.